The Biomechanics of Aging

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Distribution of Injuries Changes with Aging
*(Fragility + Frailty + Exposure)*

Injured Body Region (Fatal, All Drivers, Frontals)

- Head
- Neck
- Chest
- Abd.
- Spine
- Up. Ex.
- Lo. Ex.
- Pelvis

Over 75% of these injuries are rib fractures.

*Kent et al. 2005 AAAM*
Distribution of Injuries in People who Die Changes with Aging (Fragility + Frailty + Exposure)

Kent et al. 2005 AAAM

Risk of sustaining injury in an event (crash)

Risk of dying once injury sustained

Environment
Biomechanics of *fragility* encompass a range of length scales

- “small” scale changes ("material properties")

[Image showing structural changes with increasing age]
Biomechanics of *fragility* encompass a range of length scales

- “small” scale changes ("material properties")
- “larger” scale geometry changes

INCREASING AGE
Cortical bone area decreases

Stein and Granik, 1976
Cortical bone area decreases

Stein and Granik, 1976
Biomechanics of *fragility* encompass a range of length scales

- “smaller” scale changes (”material properties”)
- “larger” scale geometry changes
  - Decrease in thickness of cortical shell
- “large” scale geometry changes
  - Changes in rib cage morphology
Extreme Examples of Age-Related Differences in Rib Cage Geometry

Young (17 Years)  Older (64 Years)

Kent et al. 2005 Stapp
Extreme Examples of Age-Related Differences in Rib Cage Geometry

Kent et al. 2005 Stapp
Extreme Examples of Age-Related Differences in Rib Cage Geometry

Kent et al. 2005 Stapp
In conclusion...

- Mean age of U.S. population increasing by about 1 month/year.
- 2002-2012: Aging of America generated about half as many serious injuries as increased seatbelt use prevented.
- Unique set of challenges for crash protection
- Understanding the biomechanics of aging is a key part of solution
FARS Study – Results

Proportions (Drivers Killed)

- **EJECTED DRUNK/DRUGS BELTED? DELAYED DEATH?**
- **Proportion**
- **Young (age 30-45)**
- **Old (age 75+)**
- *p<0.05 for difference in proportion between groups*

Proportions:
- EJECTED: 26.2%
- DRUNK/DRUGS: 45.3%
- BELTED?: 26.9%
- DELAYED DEATH?: 31.0%
Restraint Effectiveness Drops with Age

Seat Belt Mortality Effectiveness
Adult Drivers in Frontals

- M:Belt E./air bag
- M:Belt E./no air bag
- M:Belt & air bag E.
- F:Belt E./air bag
- F:Belt E./no air bag
- F:Belt & air bag E.
“Younger” Group

Case 171158, Age 39, Female

- Vehicle went roof-first into tree. Impact at location of driver’s head. Massive intrusion at driver’s position and extensive head/neck injuries noted at autopsy.
“Older” Group

– Case 330012, Age 75, Male
  • Minor crash, died 16 days later of complications from pre-existing bowel condition

– Case 391055, Age 89, Male
  • Driver drove into house, backed up and hit house 2 more times. Died 6 days later of unknown cause.

– Several cases with “heart attack” as a co-factor or noted explicitly as cause of death

– Several cases of moderate severity, belted occupant, but elderly fatality
Gender distribution by age

Driver Gender Distribution by Age
(NASS/CDS 1994-2002, All Crash Directions, Weighted)

- Male
- Female
- Unk. or Pregnant Female

<table>
<thead>
<tr>
<th>Age Range (Years)</th>
<th>Percent Male</th>
<th>Percent Female</th>
<th>Percent Unk. or Pregnant Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-33</td>
<td>56.1</td>
<td>42.8</td>
<td>1.1</td>
</tr>
<tr>
<td>34-64</td>
<td>52.1</td>
<td>47.6</td>
<td>0.3</td>
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<tr>
<td>65+</td>
<td>45.0</td>
<td>40.0</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Gender distribution by age

Investigation thoroughness decreases with aging

- Fatal not immediately apparent
- No pictures, less intense investigation, police report often amended later
- “minor injury” whited out and “fatal” written in

Driver Gender Distribution by Age

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Cumulative $\Delta V$ Distribution by Age and Injury Severity

**p<0.001 (Bonferroni test for equality of means)
Cumulative ΔV Distribution by Age and Injury Severity

Cumulative Delta-V Frequency for Fatally Injured Drivers in Frontal Crashes (Weighted)

**p<0.001 (Bonferroni test for equality of means)**
Cumulative ΔV Distribution by Age and Injury Severity

Cumulative Delta-V Frequency for Fatally Injured Drivers in Frontal Crashes (Weighted)

- **Young adults**
- **Middle age**
- **Seniors**

NCAP and FMVSS208 cover 42-63 percentile of fatal crashes to young adults.
Cumulative ΔV Distribution by Age and Injury Severity

Cumulative Delta-V Frequency for Fatally Injured Drivers in Frontal Crashes (Weighted)

- Young adults
- Middle age
- Seniors

What about age 65+?

Test speeds:
- FMVSS 208: 48 to 34 km/h
- NCAP 208: 48 to 34 km/h
- NCAP: 56 to 43 km/h
Cumulative $\Delta V$ Distribution by Age and Injury Severity

What about age 65+?

85% of senior fatalities are below NCAP test speed
Fatality Effectiveness of Rear Seats Compared to Front Seats – Restrained Occupants

Kuppa et al., ESV, 2005
Belt technology in the driver’s seat

Kent et al., ESV, 2007
Injured Body Region (Fatal)

Injured Body Region (Fatal, All Drivers, Frontals)

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- Lo. Ex.
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Percent of Injuries

Age Group 1 (16-33)
Age Group 2 (34-64)
Age Group 3 (65+)

Injured Body Region (Fatal, All Drivers, Frontals)
Different Restraint Configurations and Injury Levels

MAIS 1+

Belt, No Airbag

Airbag, No Belt

Airbag, With Belt

Injured Body Region (Fatal, Belted Drivers without Airbag Deployment, Frontals)

Injured Body Region (Fatal, Unbelted Drivers with Airbag Deployment, Frontals)

Injured Body Region (Fatal, Belted Drivers with Airbag Deployment, Frontals)
What’s the problem, fragility or frailty? (i.e., how do we prioritize prevention vs. treatment?)

**Fragility:** Probability of sustaining an *injury* given an *exposure*

**Frailty:** Conditional probability of *death* given an *injury*

\[
\frac{P(A/B)}{P(A/B)_{20}} = \frac{\hat{R}_{\text{rel}}^{\text{death}}}{\hat{R}_{\text{rel}}^{\text{injury}}} \quad (\text{Frailty})
\]
Age-Gender Relationship in Risk (Evans 2001)

Female risk ~ 20% greater than male at all adult ages